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# Surface Morphology of Reactive Powder Concrete Containing Soil

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**Abstract:** Recent studies have revealed that concrete can be used as a media to contain As (arsenic) removed from drinking water. Concrete, which is a composite material, has been effective in solidifying hazardous wastes and contaminated soils. A research project was conducted to study the effects of uncontaminated soil and arsenic contaminated soil on the microstructure of concrete to qualitatively define the mechanisms of the encapsulation of soils containing inorganic material such as arsenic by application of solidification/stabilization technique. This research paper focused on studying the surface morphology of RPC (reactive powder concrete) containing soil.

**Keywords:** Reactive powder concrete, soil, morphology.

## 1. Introduction

The solidification/stabilization techniques reduce the mobility of hazardous substances and contaminants in the environment by physical means. This solidification/stabilization technology is considered to be one of the potentially applicable remediation technologies [1, 2]. Sludges, which leach heavy metals or other contaminants, are often stabilized to immobilize the hazardous constituents [1]. Cementitious stabilization/solidification reduces leaching of the metals into the environment [3, 4]. With chemical stabilization, TCLP (toxicity characteristic leaching procedure) extract concentrations have been reduced by several orders of magnitude. The leaching tests performed to evaluate the reuse of solid waste in cement bound construction materials are based on the principle of diffusion, which is the main leaching mechanism. Secondary

reactions taking place after hardening of the cement can influence the permeability of the cement matrix and thus enhance or limit leaching of components. Physical, chemical and micro morphological tests have been conducted to understand the dissolution/precipitation reactions and their influence on transport processes during leaching [5-7].

A research conducted by Miller et al. [8] for the treatment of arsenic contaminated sandy soils at a bench scale was conducted through the field remediation stage. The arsenic concentration in TCLP leachates ranged between 0.8 mg/L and 4.2 mg/L, and indicated low potential for ground-water contamination when the soils were treated with a mixture of Type I Portland cement and ferrous sulphate. The SEM (scanning electron microscope) micrographs showed that the solidified sample had minimum void space, and a combination of XRD (X-ray diffraction), thermal analysis, and solid-state NMR (nuclear magnetic resonance) spectroscopy

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indicated the formation of a normally hydrated cement matrix with some excess ettringite (AFt), which is  $\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12}\cdot 26\text{H}_2\text{O}$ , hydrated calcium aluminum sulfate hydroxide [8, 9]. Research work done by Dawadi et al. [10] determined compressive strength and TCLP concentrations of concrete mortar containing arsenic concentrations of 50, 100, 200 and 10,000 mg/kg. However, SEM and XRD were not used to view the microstructure and the reactions that were responsible for the increase in the setting time [10].

RPC (reactive powder concrete) has proven to be effective and reliable technology for nuclear waste blocking [11]. Results from leaching tests performed on RPC containers to evaluate their durability when used as storage for nuclear wastes showed that they are more durable, economical and can be easily maintained [12].

This research paper discusses the effect of soil on RPC, an ultra high-strength and low porosity composite material with advanced mechanical and superior physical properties. The effects of soil on the microstructure of RPC were evaluated to qualitatively define the mechanisms of encapsulation of soil.

## 2. Experimental Design

Type I/II normal Portland cement which satisfied the requirements of ASTM (American Society for Testing of Materials) C150 was supplied by Dacotah cement of South Dakota for the study.

Limestone dust and natural sand with a water absorption coefficient of 1.6% were used for casting reactive powder concrete. Fine aggregates were obtained from Hill City Materials, Rapid City, South Dakota. Rapid City Municipal water was used for the mixing. The admixtures such as Rheomac SF 100 dry, densified silica fume and Glenium 3000 NS, a HRWR

(high range water reducer) was supplied by Master Builders Inc., Cleveland Ohio. The uncontaminated soil used was commercially prepared topsoil. The experimental value of water absorption coefficient of soil was 52% [13]. The soil samples were sent to Soil Testing Laboratory, South Dakota State University for determination of organic matter and carbon content. The average percent organic matter and average percent organic carbon of soil was 19.9% and 11.52%, respectively. Sodium arsenate ( $\text{Na}_2\text{HAsO}_4\cdot 7\text{H}_2\text{O}$ ) with molecular weight 311.89 g/mol was used for encapsulation in soil. RPC specimens of size 2 in  $\times$  2 in  $\times$  2 in (51 mm  $\times$  51 mm  $\times$  51 mm) were cast according to ASTM C 305 procedure [14].

## 3. Results

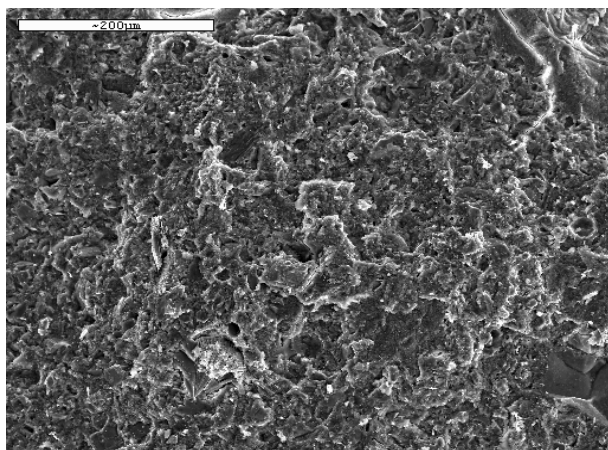
### 3.1 SEM Results on RPC Control Mix

An RPC control mix (RPC-1) was cast using cement, fine sand, silica fume, limestone fines, HRWR (high range water reducer) and water. Table 1 shows the proportion of materials (mass ratio with respect to cement) used for casting reactive powder concrete.

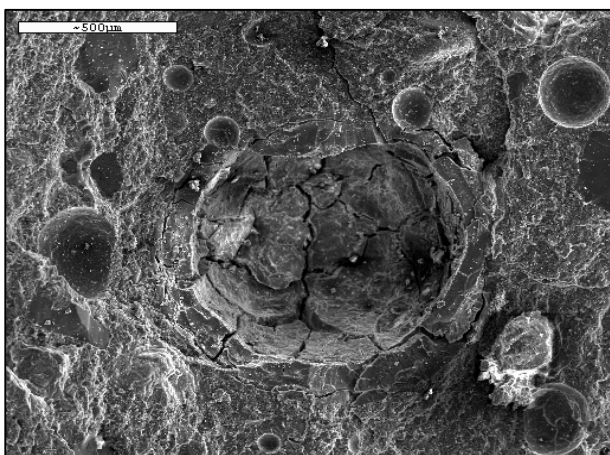
The microstructure of RPC-1 was viewed under SEM. Figs. 1-3 show the microstructure of RPC-1 after 7-day curing. Fig. 1 is a section of RPC-1 with no air voids and Fig. 3 is another section of the sample with air voids. The presence of air voids could increase the permeability and adsorption capacity of concrete while decreasing the strength. Fig. 2 shows the formation of ettringite and alkali silica gel within a void. Cracks observed were due to the ettringite formation in the voids, which could be due to silica reactions with hydroxides, or presence of silica fume clumps in concrete. The presence of silica gel, which induced ettringite formation, could lead to the

**Table 1** Mix proportions used for casting sample, RPC-1.

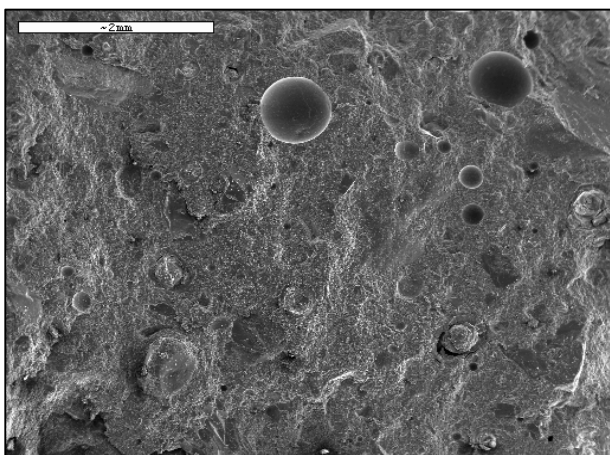
Mix No.	Cement	Water cement ratio	Fine sand (mass ratio with respect to cement)	Silica fume (mass ratio with respect to cement)	Limestone fines (mass ratio with respect to cement)	Superplasticizer (% of total weight of aggregates)
RPC-1	1	0.275	1.3375	0.3875	0.3	1.8



**Fig. 1** RPC-1 at 200  $\mu\text{m}$  magnification.



**Fig. 2** Formation of ettringite and alkali silica gel in void at 500  $\mu\text{m}$  magnification.



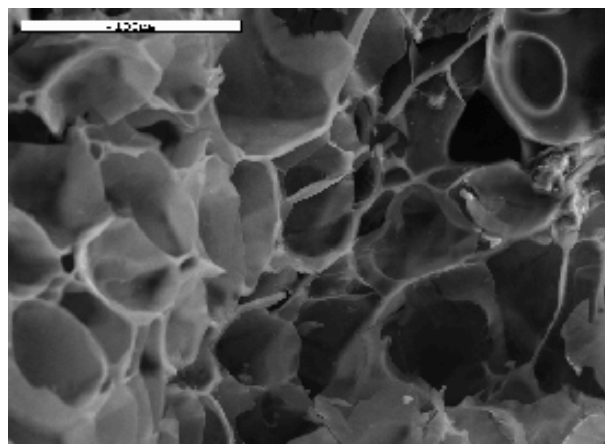
**Fig. 3** Formation air voids in RPC-1 at 2 mm magnification.

formation of cracks and decrease in concrete strength. Calcium, silica, aluminum, sodium, phosphorus, and sulfur were all detected.

### 3.2 SEM Results on RPC Containing Uncontaminated Soil

Two RPC mixes were cast using topsoil with RPC-1 as the control mix. Concrete sample RPC-S1 was prepared with soil proportion of 10% of sand content and sample RPC-S2 was prepared with soil of 100% of sand content. The microstructures of the RPC-S1 at 7 day curing and RPC-S2 at 7-day and 28-day curing were viewed under SEM to examine the difference in the microstructure due to the presence of the lowest and the highest soil proportions.

The organic matter rich in calcium in the form of cells was commonly observed in both of the specimens containing soil (Fig. 4). Quartz, and feldspar, typical components of soil were also observed. Silica gel with cracks was observed which could be due to shrinkage (Fig. 5). Formation of ettringite, as small needles, was also observed (Fig. 6). Delayed ettringite formation is considered to be the cause for the concrete deterioration because growing ettringite crystals induce stress, which cracks the hardened concrete [15]. Although ettringite was identified, its presence did not appear to correlate with concrete soundness. This confirmed that if ettringite occurs as partly filling voids, it does not contribute to concrete deterioration. Formation of calcium hydroxide was also observed in the form of blade and plate like structures shown in Figs. 7-8.



**Fig. 4** Cells of organic matter rich in calcium observed in concrete containing uncontaminated soil at 150  $\mu\text{m}$  magnification.

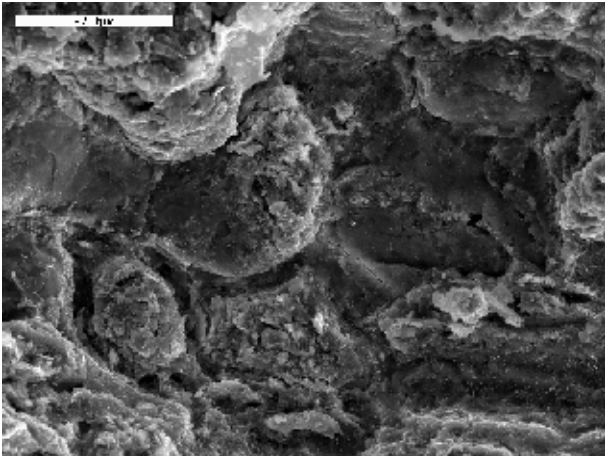


Fig. 5 Silica gel with cracks observed commonly in RPC-S1 and RPC-S2 at 2  $\mu$ m magnification.

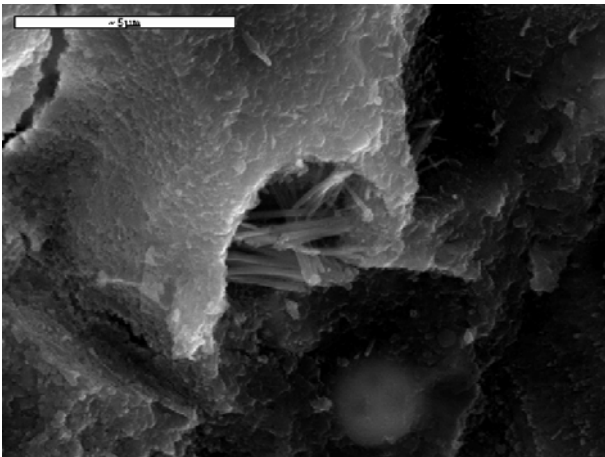


Fig. 6 Formation of ettringite in form of needles at 5  $\mu$ m magnification.

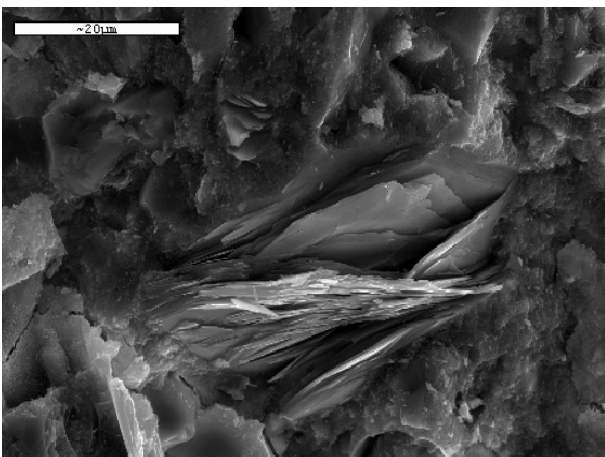


Fig. 7 Formation of calcium hydroxide having blade like structure at 20  $\mu$ m magnification.

The increase in soil content resulted in inadequate bonding between matrix and soil and also an increase in the number of voids. In mix RPC-S2 cured at 7

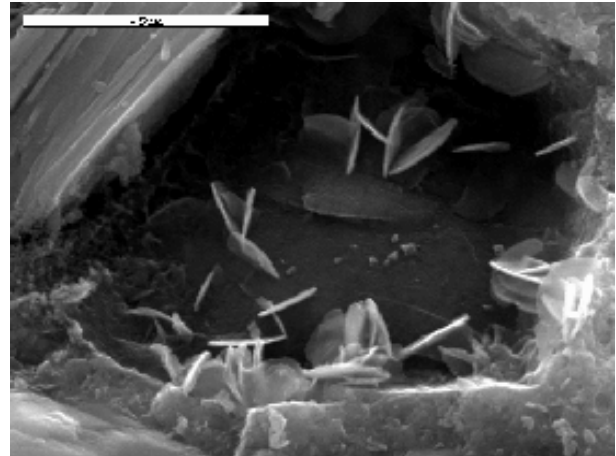


Fig. 8 Formation of calcium hydroxide having plate like structure at 5  $\mu$ m magnification.

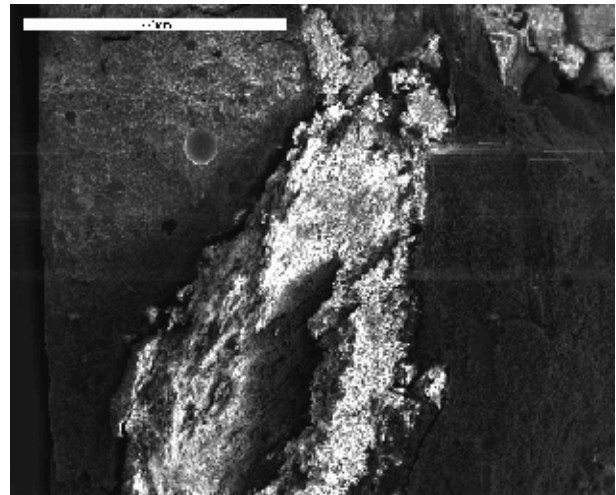


Fig. 9 Inadequate bonding between the matrix and organic matter observed in RPC-S2 at 1  $\mu$ m magnification.

days, the organic matter appeared as if it were pulling apart from the matrix leading to internal cracks between matrix and organic matter, clearly shown in Fig. 9. The evidence of inadequate bonding is also shown in Fig. 10 where the wood, present in organic soil, was enlightened since the electrons coming from SEM failed to pass through it due to the gap between the wood and the matrix.

When the sample RPC-S2 was viewed at 28 days, a lot of carbon with oxygen and calcium and formation of dolomite were observed which showed that with curing, the organic matter formed compounds with the matrix. Fig. 11 shows the presence of carbon with the combination of oxygen and calcium followed by a spectrum in Fig. 12.



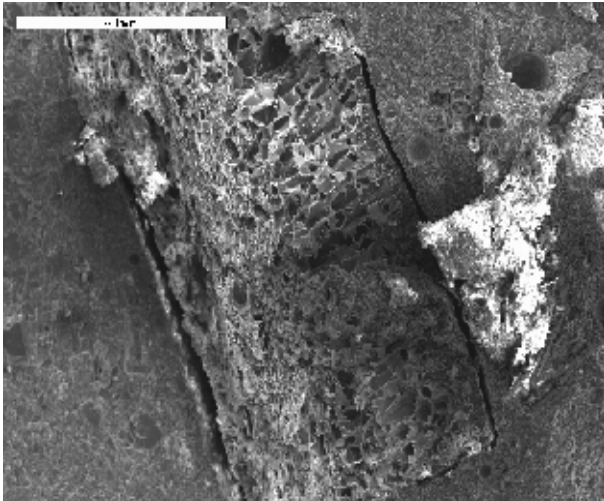


Fig. 10 Internal crack between the matrix and organic matter observed in RPC-S2 at 1 μm magnification.

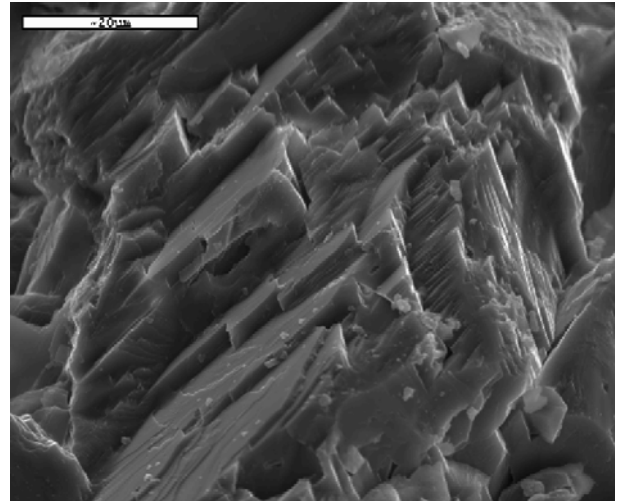


Fig. 13 Formation of dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ) at 28-day curing at 20 μm magnification.

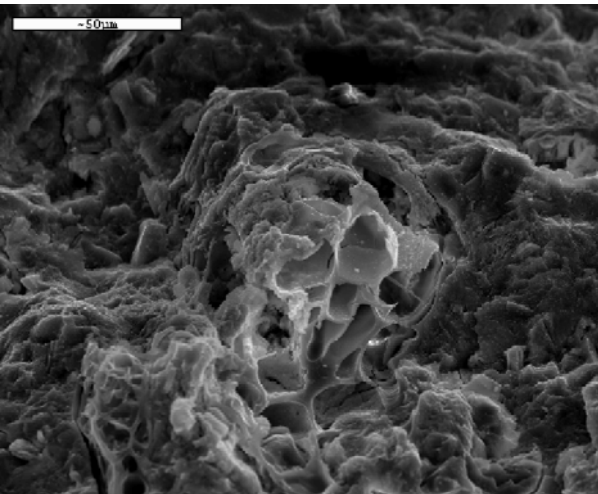


Fig. 11 Presence of carbon with combination of oxygen and calcium at 28-day curing at 50 μm magnification.

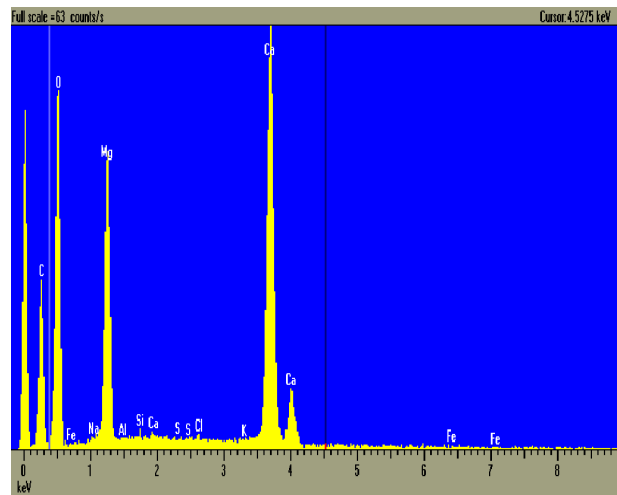


Fig. 14 The spectrum showing calcium, magnesium and oxygen peaks.

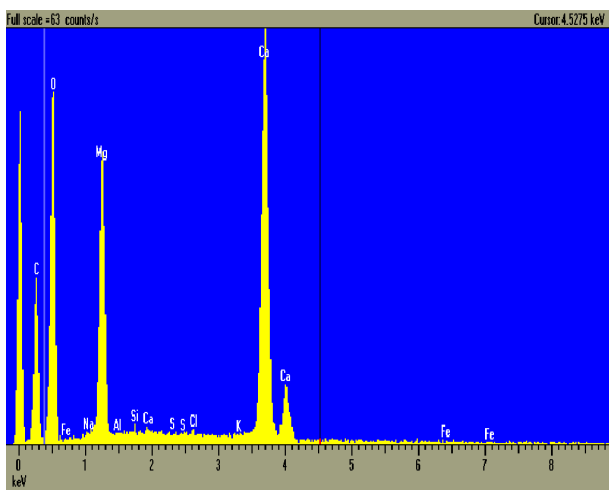


Fig. 12 The spectrum showing the carbon, oxygen and calcium peaks.

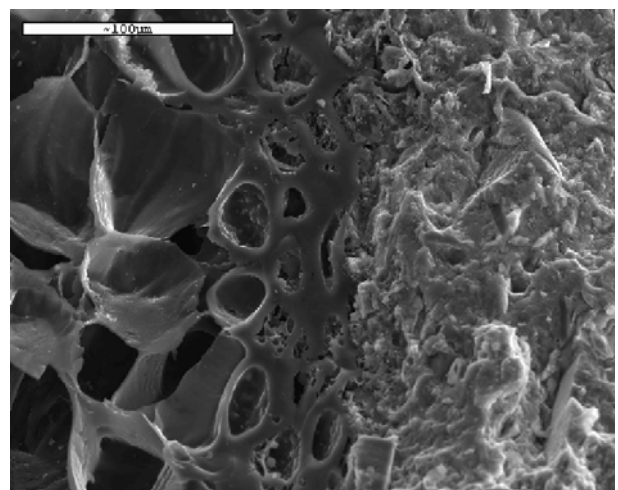


Fig. 15 The bonding between the organic matter and matrix at 28 days at 100 μm magnification.

**Table 2 X-ray diffraction analysis report on sample containing inorganic soil.**

Component	Chemical formula	Weight (%)
Quartz	SiO <sub>2</sub>	29.4 + 3.1
Calcite	CaCO <sub>3</sub>	25.0 + 3.0
Calcium silicates	Ca <sub>2</sub> SiO <sub>4</sub> & Ca <sub>3</sub> SiO <sub>5</sub>	14.5 + 2.5
Portlandite	Ca(OH) <sub>2</sub>	5.2 + 0.8
Microcline (Feldspar)	KAISi <sub>3</sub> O <sub>8</sub>	16.6 + 1.8
Albite (feldspar)	NaAlSi <sub>3</sub> O <sub>8</sub>	7.3 + 0.9
Muscovite	KAl <sub>2</sub> (AlSi <sub>3</sub> O <sub>10</sub> )(OH) <sub>2</sub>	2.0 + 1.0
Dolomite	CaMg(CO <sub>3</sub> ) <sub>2</sub>	Trace

Fig. 13 shows the formation of dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>) followed by a spectrum in Fig. 14 showing the peaks rich with calcium, magnesium and oxygen. The bonding between the matrix and the organic matter improved at 28 days, which was evident from Fig. 15, showing the bonding between the wood and the matrix.

X-ray diffraction analysis was used to identify the mineral phases in a powdered sample of RPC-S1. The results in Table 2 summarize the list of compounds formed with weight percent. Microcline, albite and muscovite compounds were formed due to the presence of organic soil.

#### 4. Conclusions

The increase in soil content in concrete mortar resulted in the increase of number of voids and inadequate bonding between cement paste and organic soil. Ettringite formation resulting from soil encapsulation did not appear to contribute to concrete deterioration as it occurred as partially filled voids. Soil addition resulted in increased voids, which could improve arsenic adsorption, but also contributed to inadequate bonding between the matrix and organic matter, which could reduce concrete soundness. Microcline, albite and muscovite were typical compounds observed due to the presence of organic soil.

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